IIP Update: A Packaged Coherent Doppler Wind Lidar Transceiver

“Doppler Aerosol WiNd lidar (DAWN)”

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to

Working Group on Space-Based Lidar Winds
Welches, OR
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Also many thanks to Brian Killough, Keith Murray, Garnett Hutchinson, and Ken Anderson

IIP Motivation

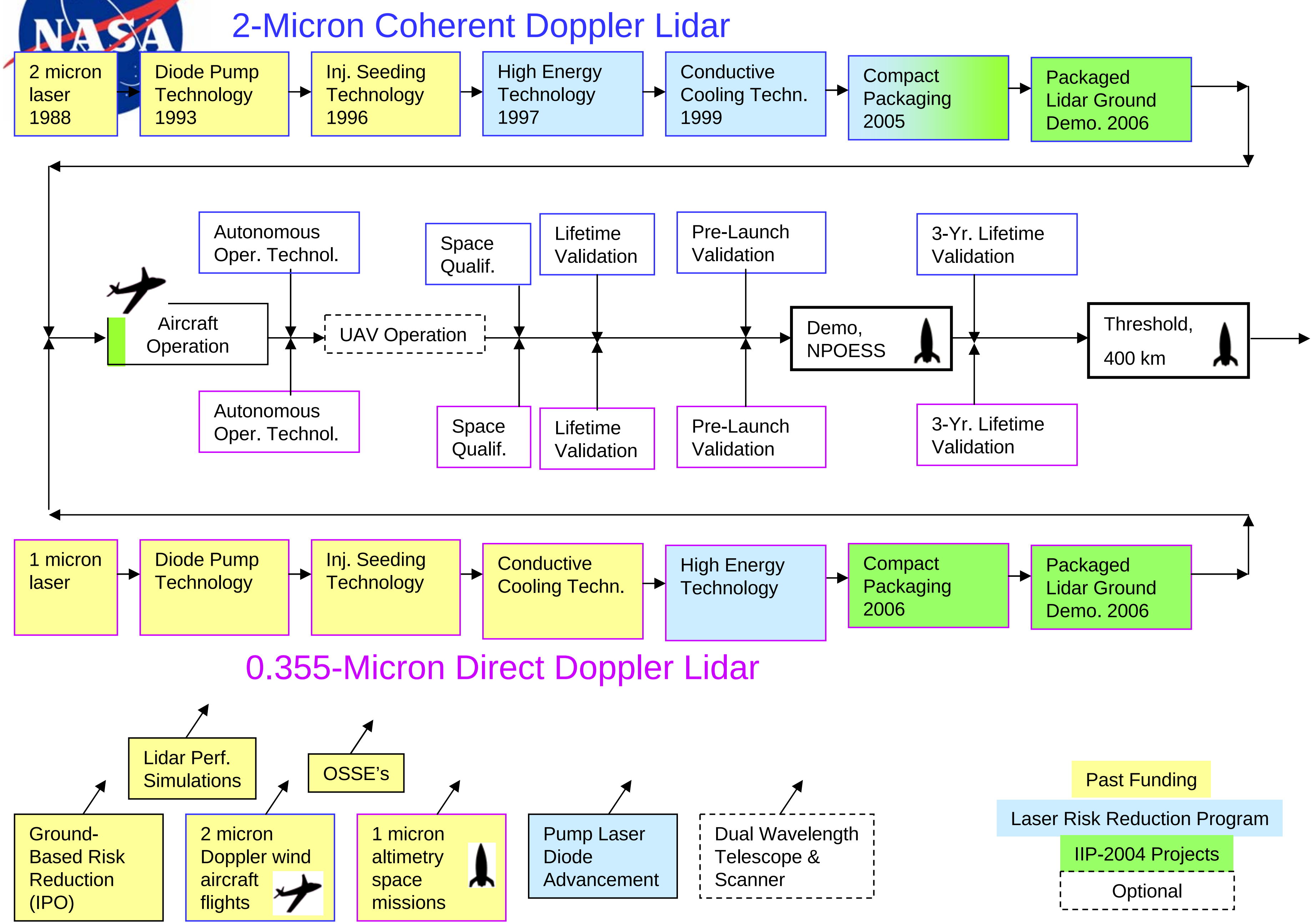
	Mission	Measurement	Technique	Technology
Primary	Science: Weather, Climate	Earth Vertical **Wind** Profiles	Scanning Doppler Lidar	Pulsed, 2-Micron, Ho Laser
Secondary	Science: Climate	Earth Vertical **CO_2** Concentration Profiles	Scanning DIAL Lidar	Pulsed, 2-Micron, Ho Laser
	Science & Exploration: Atmos. Char., EDL	Mars Vertical **Density** Profiles	DIAL Lidar (CO_2)	Pulsed, 2-Micron, Ho Laser
	Science & Exploration: Atmos. Char., EDL	Mars Vertical **Wind** Profiles	Scanning Doppler Lidar	Pulsed, 2-Micron, Ho Laser
	Science: Climate	Earth Vertical **Aerosol** Concentration Profiles	Backscatter Lidar	Pulsed, 2-Micron, Ho Laser
	Science & Exploration: Atmos. Char., EDL	Mars Vertical **Dust** Profiles	Backscatter Lidar	Pulsed, 2-Micron, Ho Laser

IIP Abstract

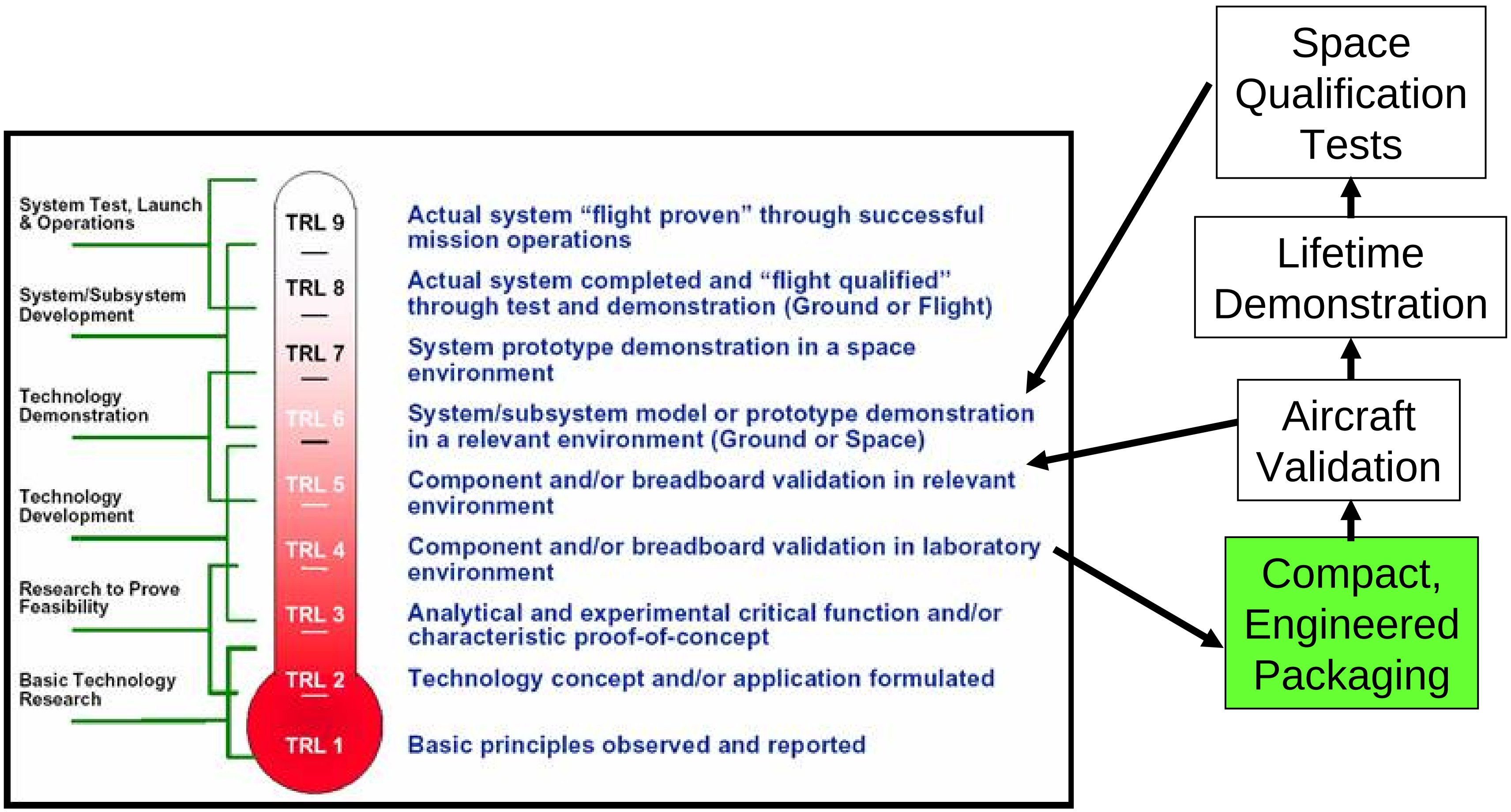
The state-of-the-art 2-micron coherent Doppler wind lidar breadboard at NASA/LaRC will be engineered and compactly packaged consistent with future aircraft flights. The packaged transceiver will be integrated into a coherent Doppler wind lidar system test bed at LaRC. Atmospheric wind measurements will be made to validate the packaged technology.

This will greatly advance the coherent part of the hybrid Doppler wind lidar solution to the need for global tropospheric wind measurements.

IIP and the Global Tropospheric Wind Profiles Roadmap



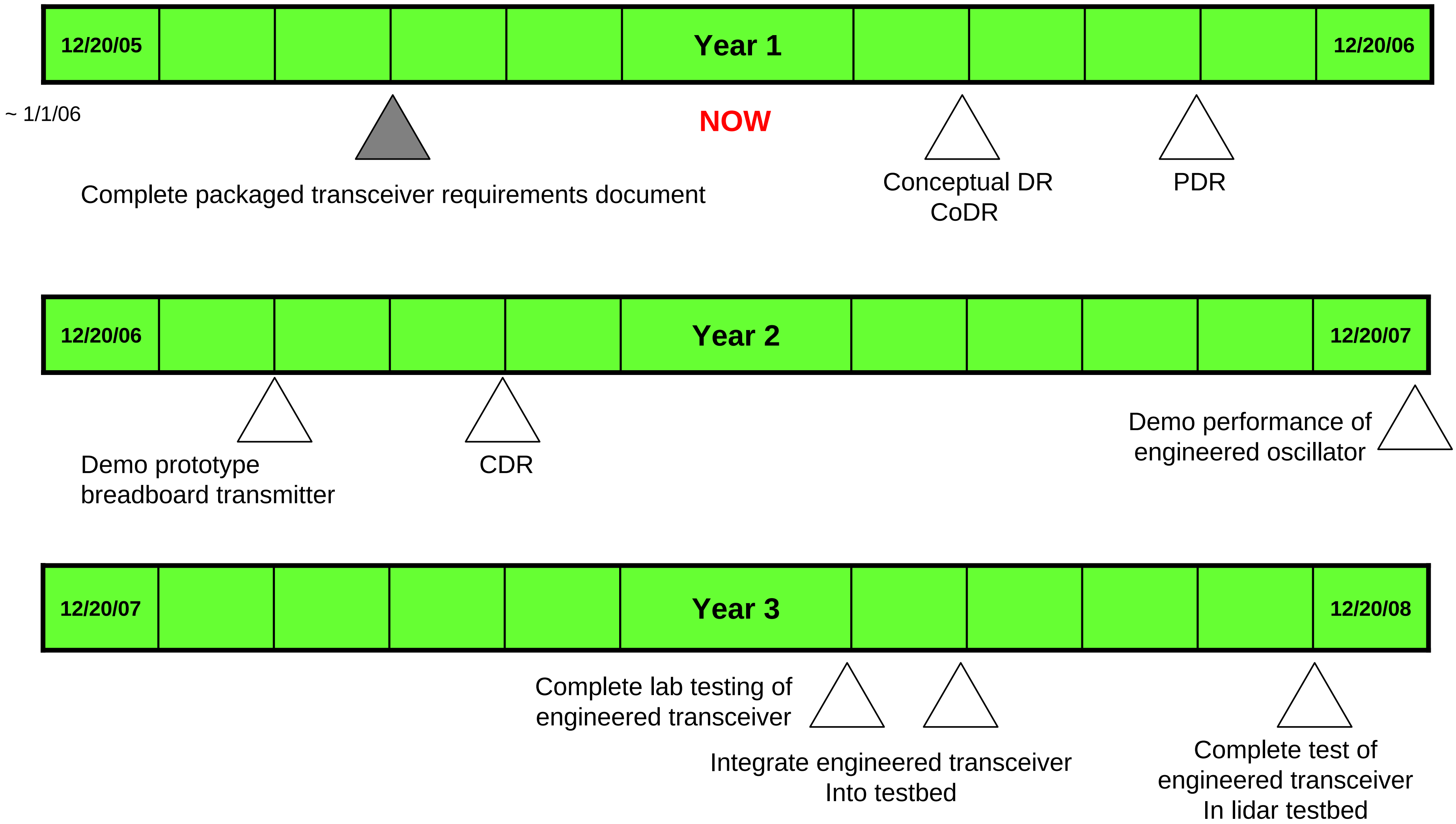
IIP TRL Advancement
“4 → 5”



IIP and the LaRC Development of Pulsed, 2-Micron Laser Technology For Space

Category	Sub-Category/Date	6/02	9/02	2/03	4/03	11/03	2/05	12/05	LRRP	**IIP**	SPACE DEMO
Demonstrated (Side-Pumped, LuLiF)	Pulse Energy (J) (in double pulse)	0.135	0.355 /0.6	0.095	0.626/ 1.05	0.1/ 0.073	1/1.5	1.2		**0.25**	0.25
	Pulse Rate (Hz)	2	2	10	2	2/10	2	2		**10**	5-10
	Efficiency (%) (O-O)	3.65	3.66	2.57	4.10	2.78	5/6.2	6.5			
Laser Component	Oscillator	✓	✓	✓	✓	✓	✓	✓		✓	✓
	Preamplifier						✓				
	Amplifiers		1 x 2-pass		2 x 2-pass		2 x 2-pass	2 x 2-pass	✓	**1 x 2-pass**	1 x 2-pass
Laser Mode	Q-Switched	✓	✓	✓	✓	✓	✓	✓		✓	✓
	Double Q-Switched		✓		✓	✓	✓				
	Injection Seeded=SLM			✓						✓	✓
Cooling	All liquid				amp						
	Partially conductive	✓	✓	✓	osc		✓	✓		✓	
	All cond w/o heat pipe										
	All cond w/ heat pipe					✓			✓		✓
Pump Diodes	C Package				amp						
	A package	✓	✓	✓	osc	✓	✓	✓	✓		
	AA package									✓	
	G package										✓
Packaging	Laboratory Table	✓	✓	laser	✓	laser	✓	✓			
	Compact, Engineered			head		head			head	✓	✓

IIP- Milestones & Schedule

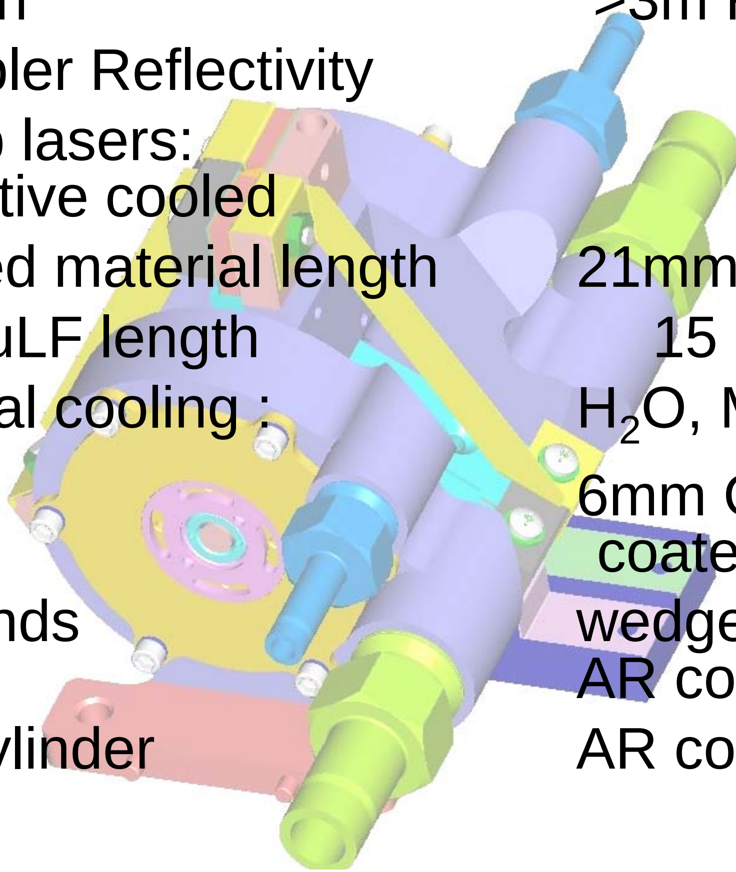


IIP Packaged Transceiver Requirements

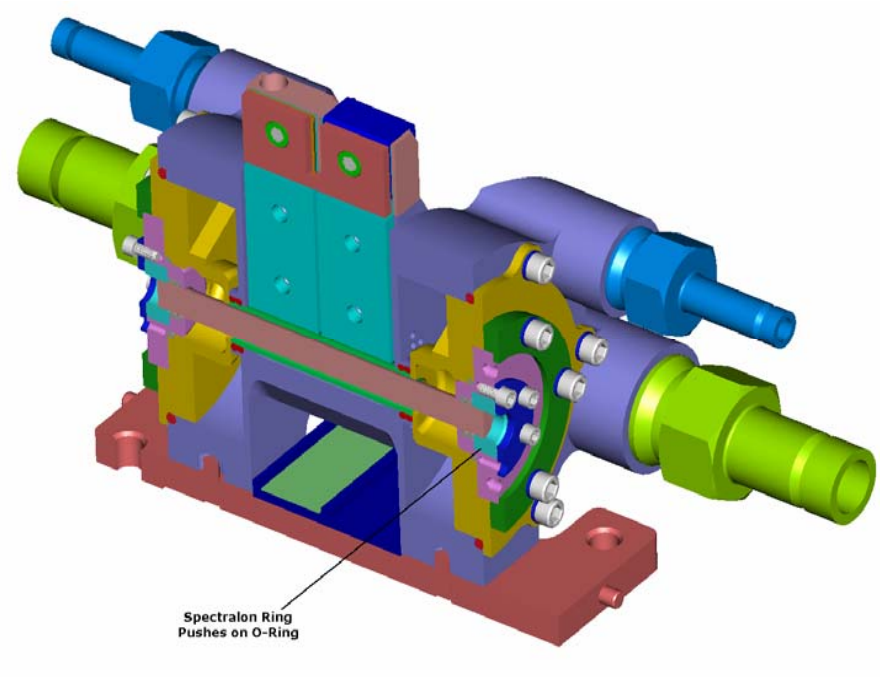
Category	Requirement	Goal (if different) and/or Space Requirement	Reason
Laser Architecture	Master Oscillator Power Amplifier (MOPA)		High energy, beam quality, optical damage
Laser Material	Ho:Tm:LuLiF		High energy, high efficiency, atmospheric transmission
Nominal Wavelength	2.053472 microns		Atmospheric transmission
Pulse Energy	150 mJ	250 (space)	Computer modeling of measurement performance
Pulse Repetition Frequency	10 Hz	10-20 (space)	Shot accumulation, optimum laser diode array lifetime
Pulse Beam Quality	< 1.4 x diffraction limit		Heterodyne detection efficiency influence
Pulse Spectrum	Single Frequency	Few MHz (space)	Frequency estimation process
Injection seeding success	95%	99%	Shot accumulation
Laser Heat Removal	Partial Conductively Cooled	FCC (space)	No liquid lines in space
Packaging	Compact, engineered	Aircraft ready Space qual. (space)	As ready as possible for aircraft follow on

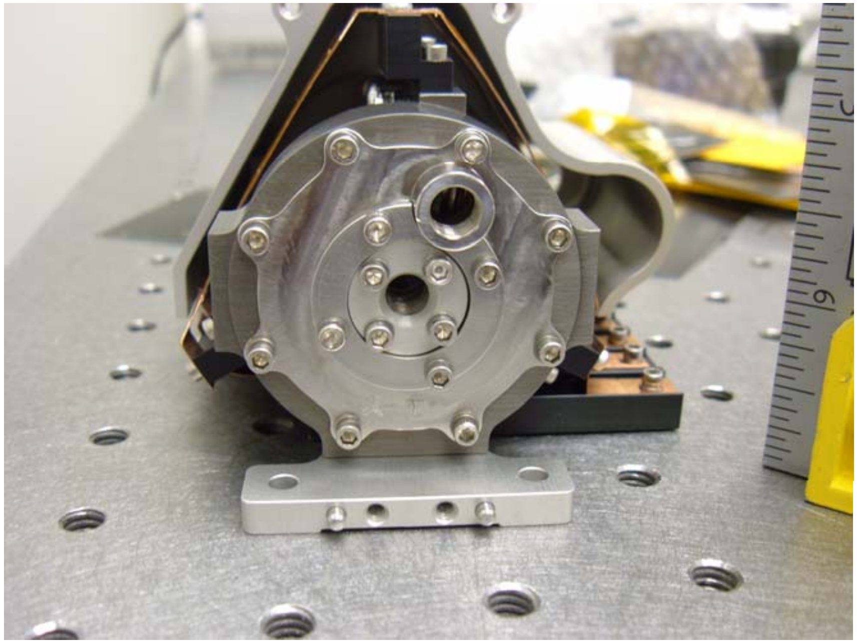
Oscillator features

- Injection seeded
- Cavity length >3m Ring
- Output coupler Reflectivity ~70%
- Diode pump lasers: 36 bars 100W/b conductive cooled
- crystal doped material length 21mm
- undoped LuLF length 15 mm
- Laser crystal cooling : H_2O, Methanol
- Tube size: 6mm OD 5mm ID AR coated for 792nm
- Laser rod ends wedged 0.5° along c-axis AR coated for 2.053μm
- Laser rod cylinder AR coated for 792nm



Oscillator Head

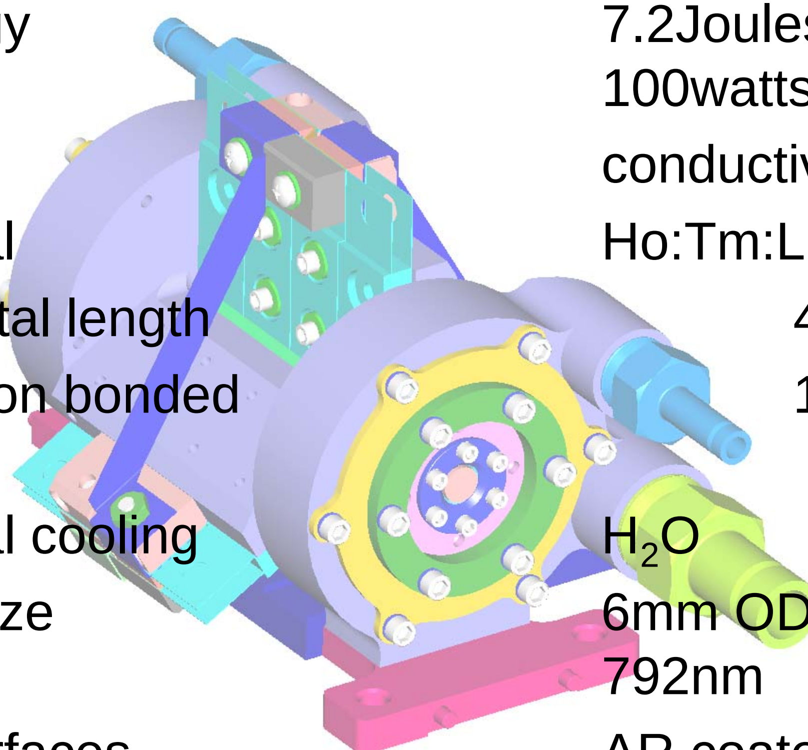




Oscillator cavity length

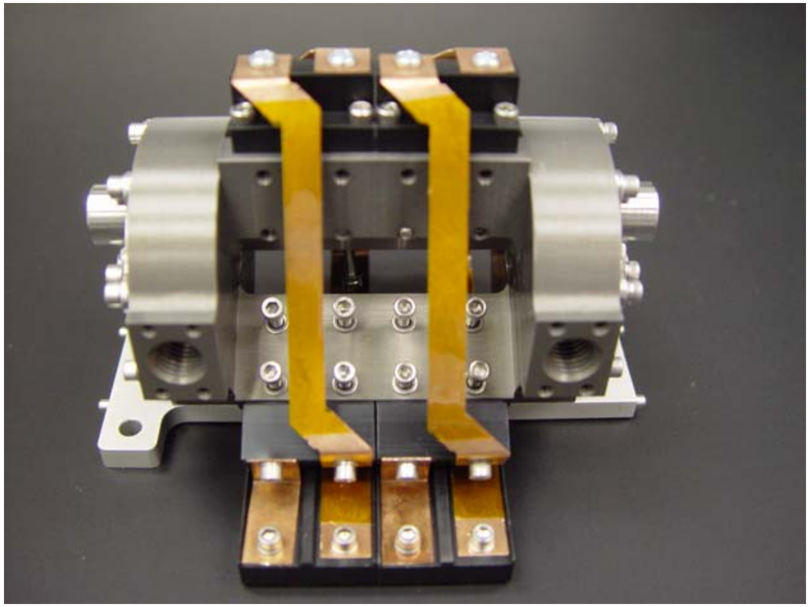
- Long cavity length is needed to obtain narrow linewidth
  - Pulse length is one of the critical parameters of a coherent Lidar.
  - A short pulse compromises frequency resolution while a long pulse compromises range resolution.
  - To meet the pulse length requirement, the oscillator length was changed from 2m to 3m. It prolongs the pulse width to near 200ns
  - The resonator has six mirrors and 8 bounces.

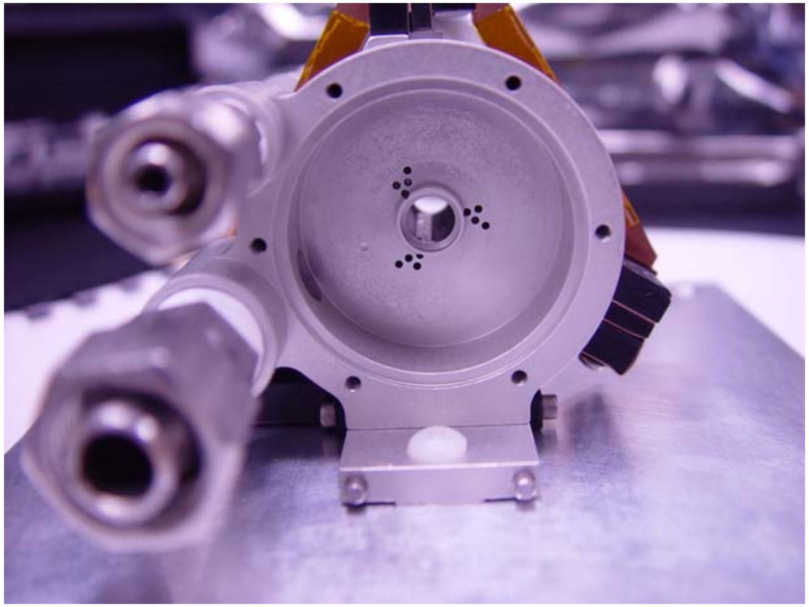
Amplifier features



• Pump energy	7.2Joules12x6 bar arrays with 100watts/bar
• Diode laser	conductive cooled ‘AA’ Pkg
• Laser crystal	Ho:Tm:LuLF 0.5% Ho 6%Tm
• Doped Crystal length	41mm
• Ends diffusion bonded crystals	15 mm undoped LuLF
• Laser crystal cooling	H_2O
• Flow tube size	6mm OD 5mm ID AR coated 792nm
• Rod end surfaces	AR coated for 2.053μm
• Laser cylinder	AR coated for 792nm
• Path configuration	double pass

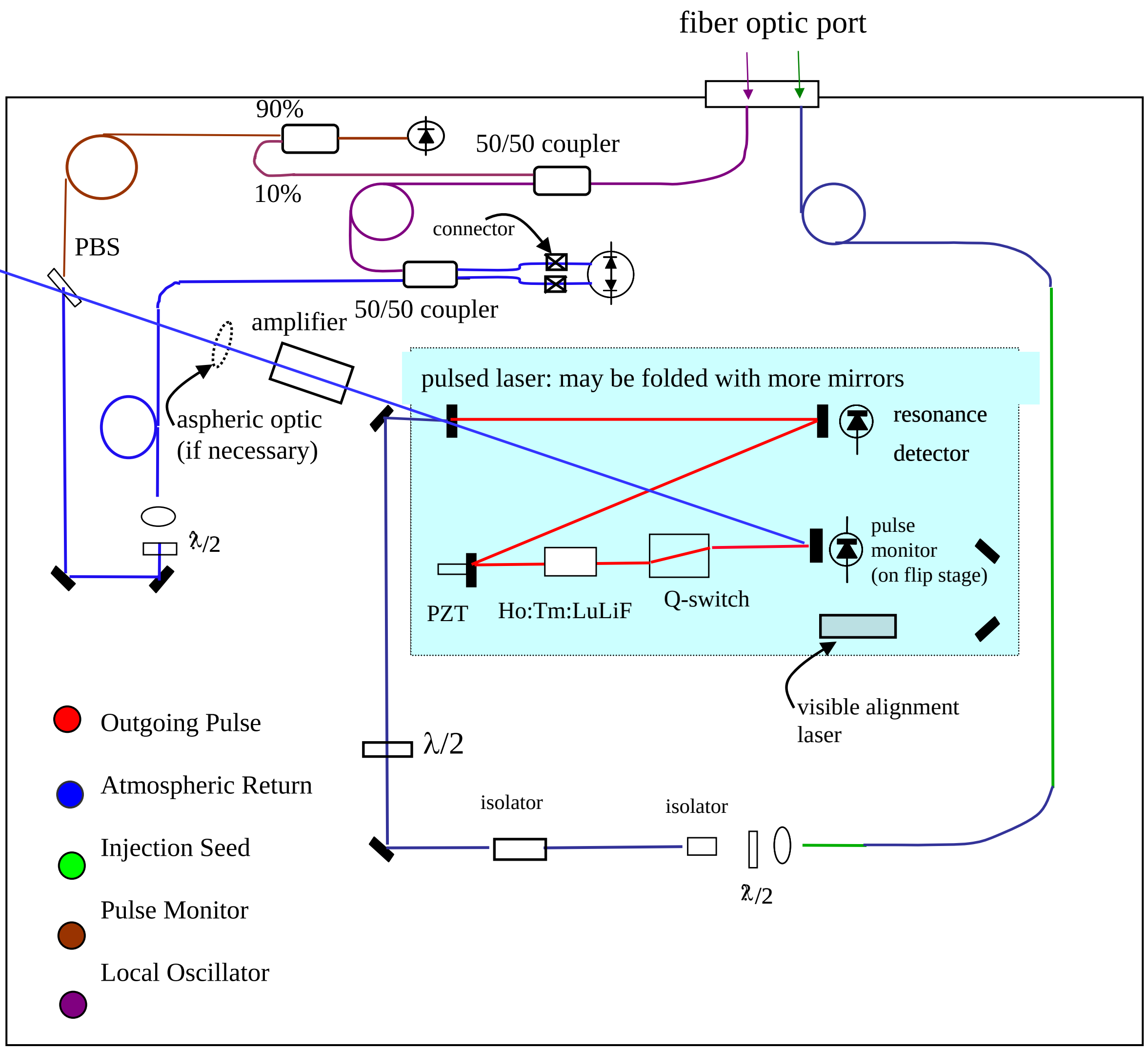
Amplifier Module





Proposed Transceiver "Box"

- Modular approach with injection seed & local oscillator separate from transceiver.
- Separate seed/LO allows flexibility to adapt to 4 measurements scenarios:
  - -simple, fixed frequency LO for ground or low platform speed.
  - - higher intermediate frequency for high platform speed
  - - swept LO for very high platform speed.
  - -DIAL of CO_2

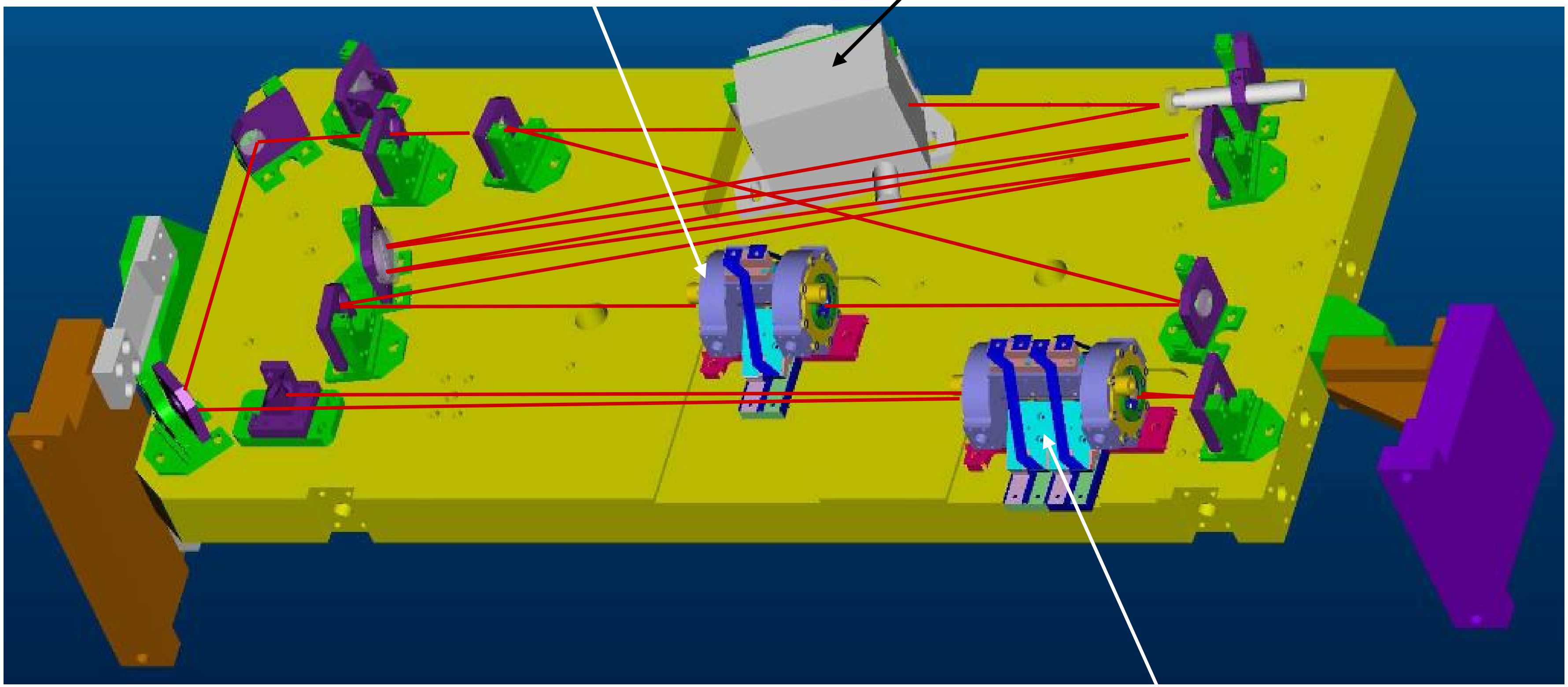


Note: only optical paths are represented; electrical and water paths are not shown.

LRRP Pulsed, 2-Micron Laser Transmitter Opto-Mechanical Design

Oscillator Laser Head

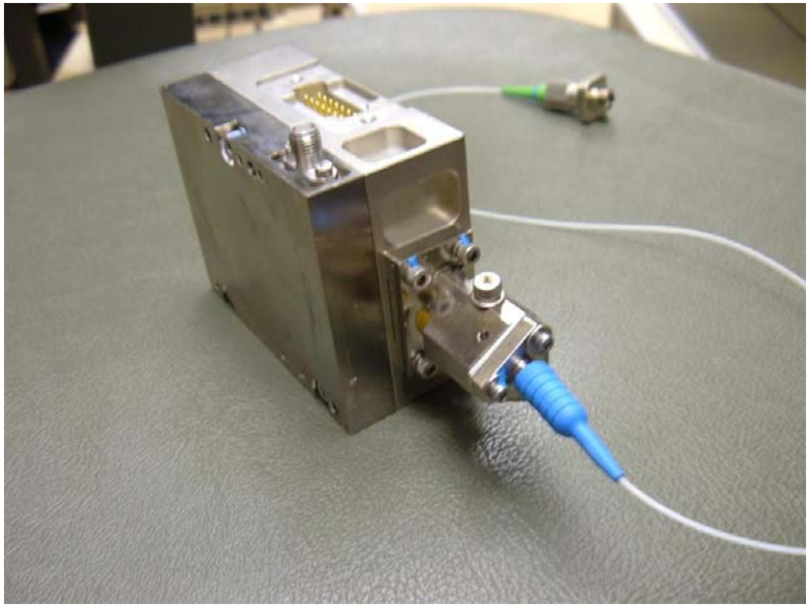
AO Q-switch



Amplifier Laser Head

- 3-m, bow-tie, unidirectional master oscillator power amplifier
- Seeding and receiver optics on reverse side
- Expect this hardware in about 8 weeks for LRRP

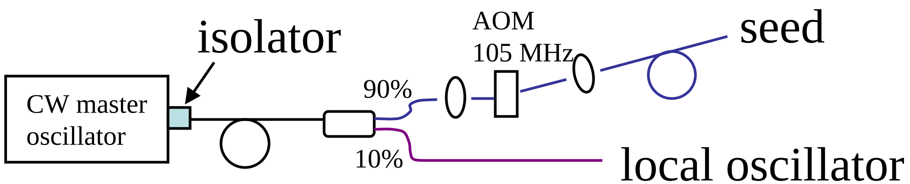
Seed Laser



CW seed laser

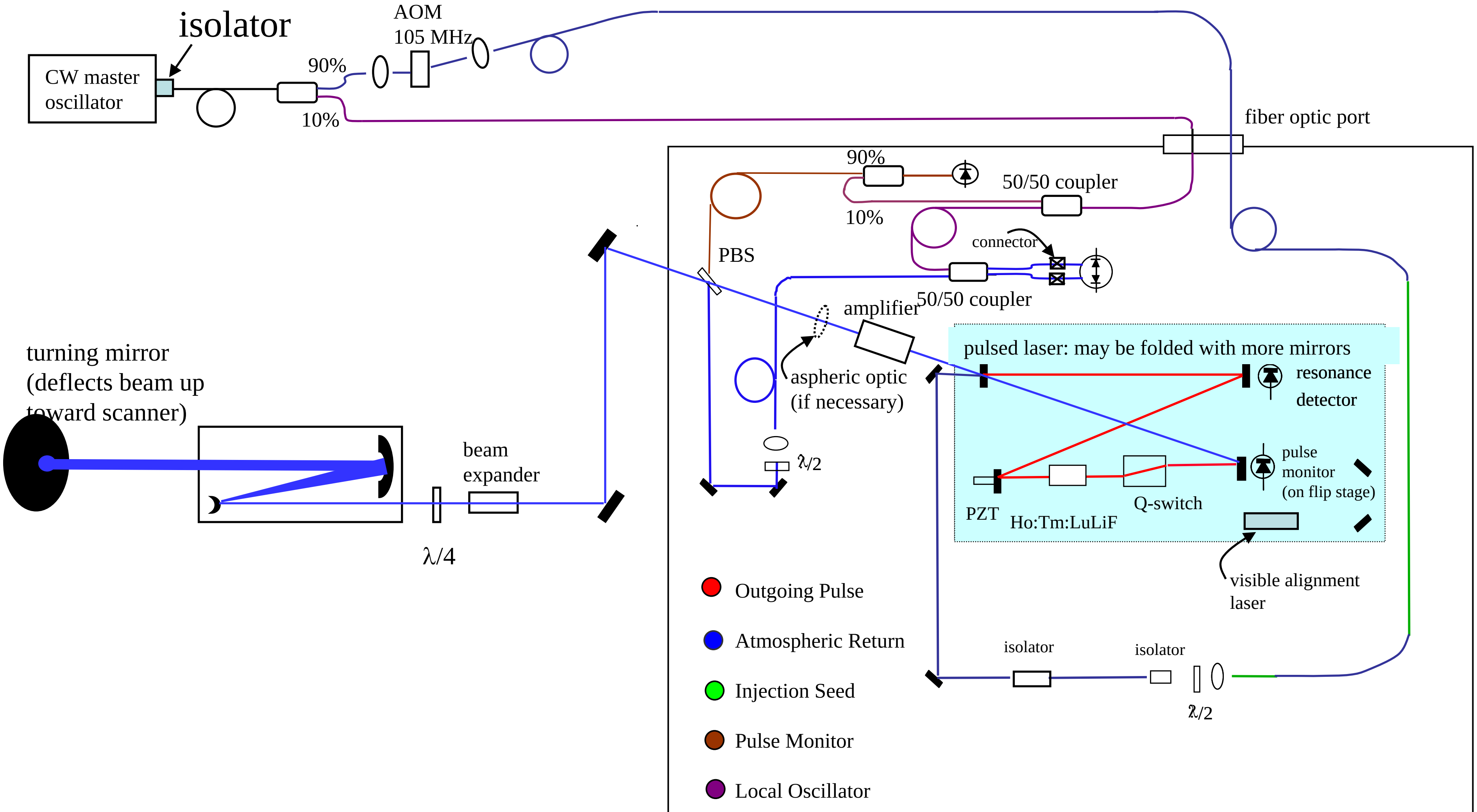
Seed laser driver

Seed/LO Option 1

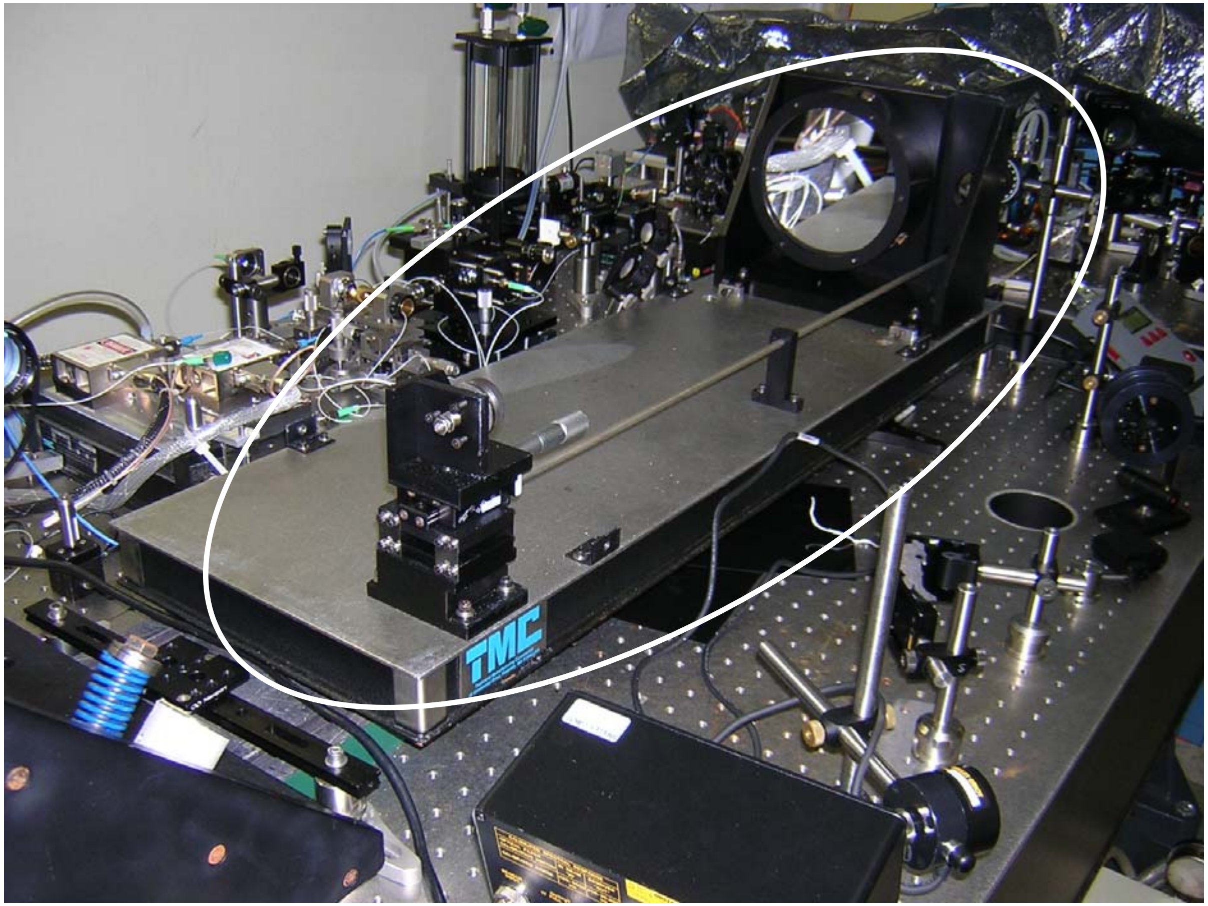


• baseline design for ground-based implementation.
• recommended for IIP demonstration.
• fiber-to-free space through AOM then back to fiber is disadvantageous—looking into fiber optic pigtailed AOM.
• could be packaged in rack-mount breadboard with fan for cooling (need thermal analysis).

Test Bed: Putting it all Together

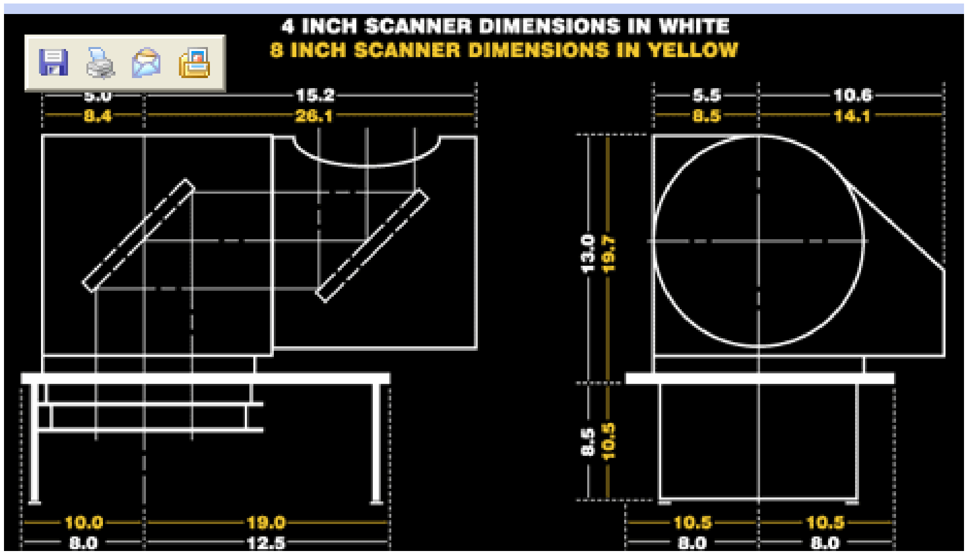


VALIDAR Telescope



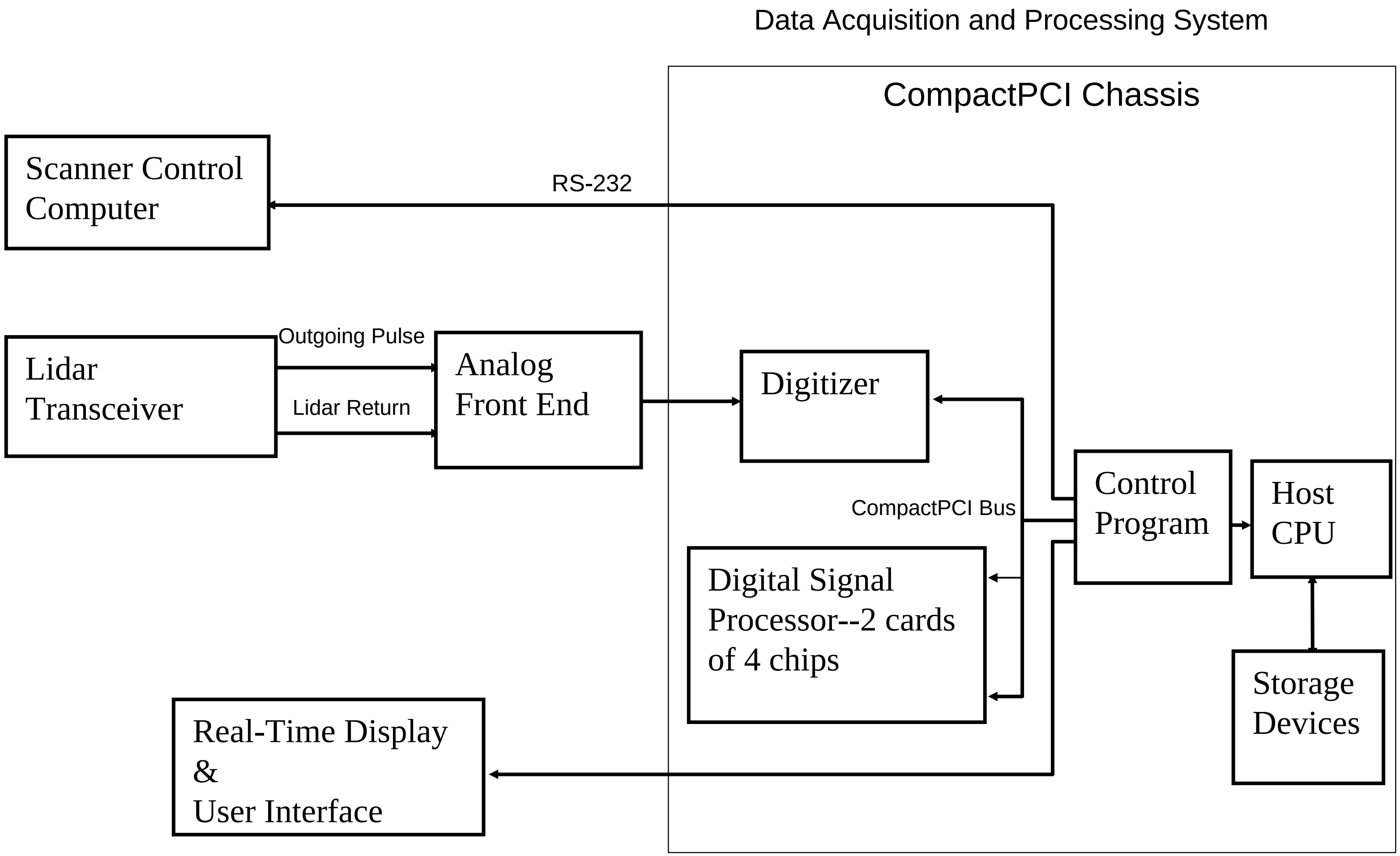
- off axis Dall-Kirkham design.
- 6-inch aperture
- 20X expansion

VALIDAR Scanner

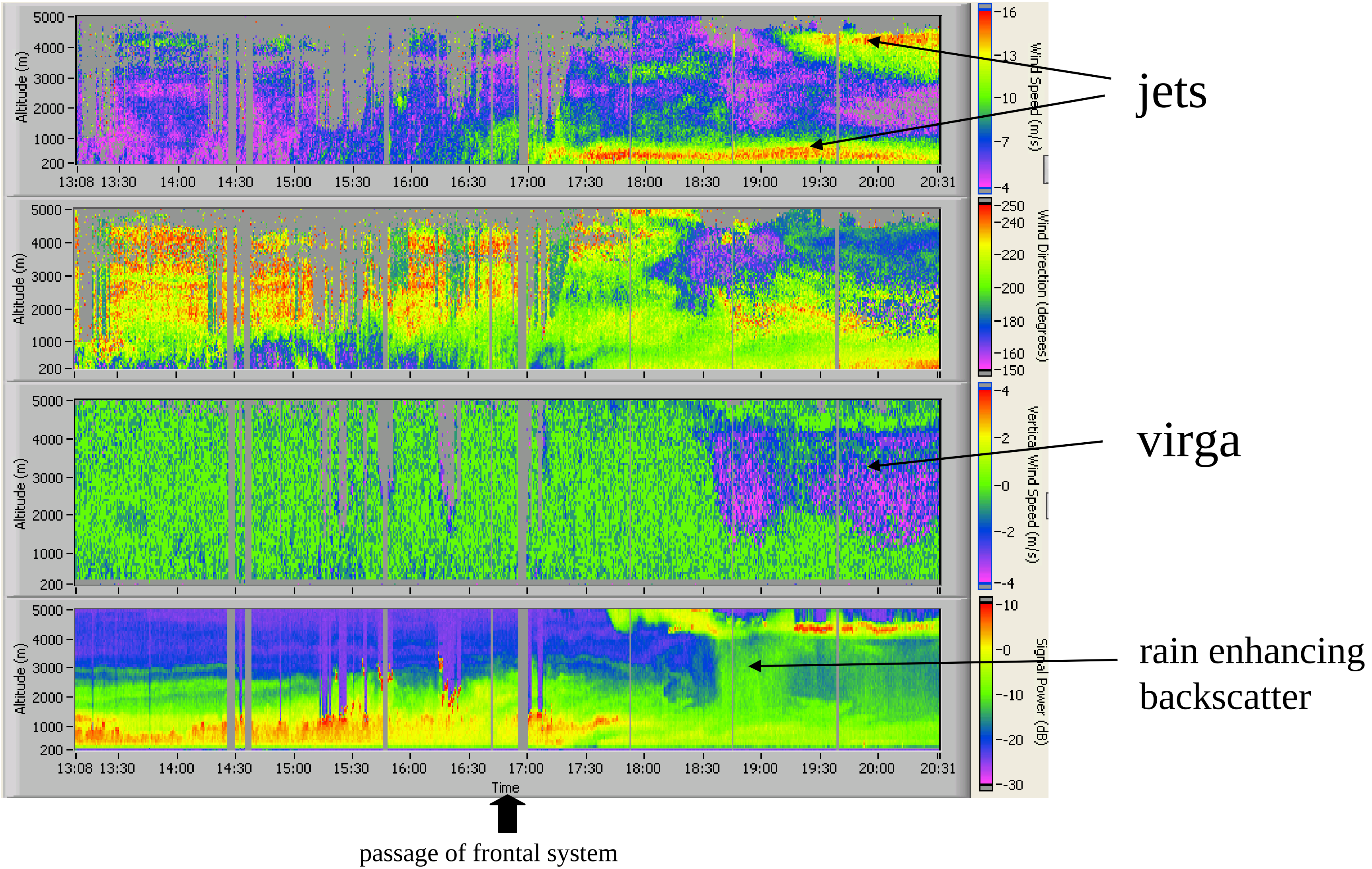


- scanner is mounted on roof of laboratory trailer.
- 8-inch clear aperture.
- can be pointed or scanned in elevation/azimuth for hemispherical coverage.
- linked to data acquisition computer for automated profiling of wind.

Data Acquisition and Processing (already built)



Atmospheric Measurements (will be better than this VALIDAR sample)

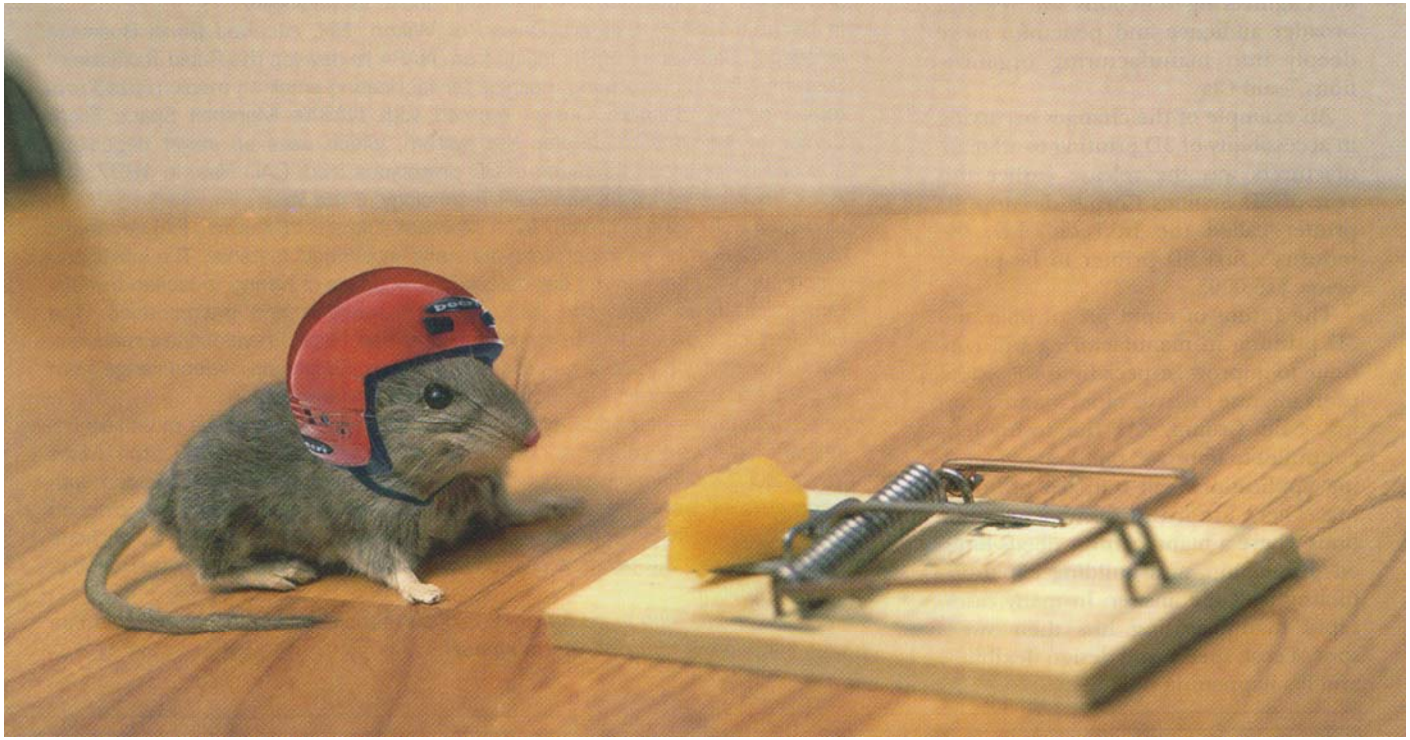


Summary

- IIP project 6 months into 36 month effort
- On schedule and budget to date
- Leveraging LRRP work on compact laser in 05 and 06
- Plan on significant steps of compact, engineered packaging of state-of-the-art laser/lidar technology. TRL definitions do not reveal significant progress.
- Companion IIP at GSFC for noncoherent Doppler wind lidar will complement this project to permit hybrid DWL on aircraft and then in space
- Project very consistent with findings of NASA/ESTO Laser/Lidar Technology Requirements Working Group results (FY06). To be issued in final report
- Anticipate strong endorsement of global winds by NAS decadal study on earth sciences
- Same technology promises additional applications for earth and Mars

Project Motto 1

- Be Prepared



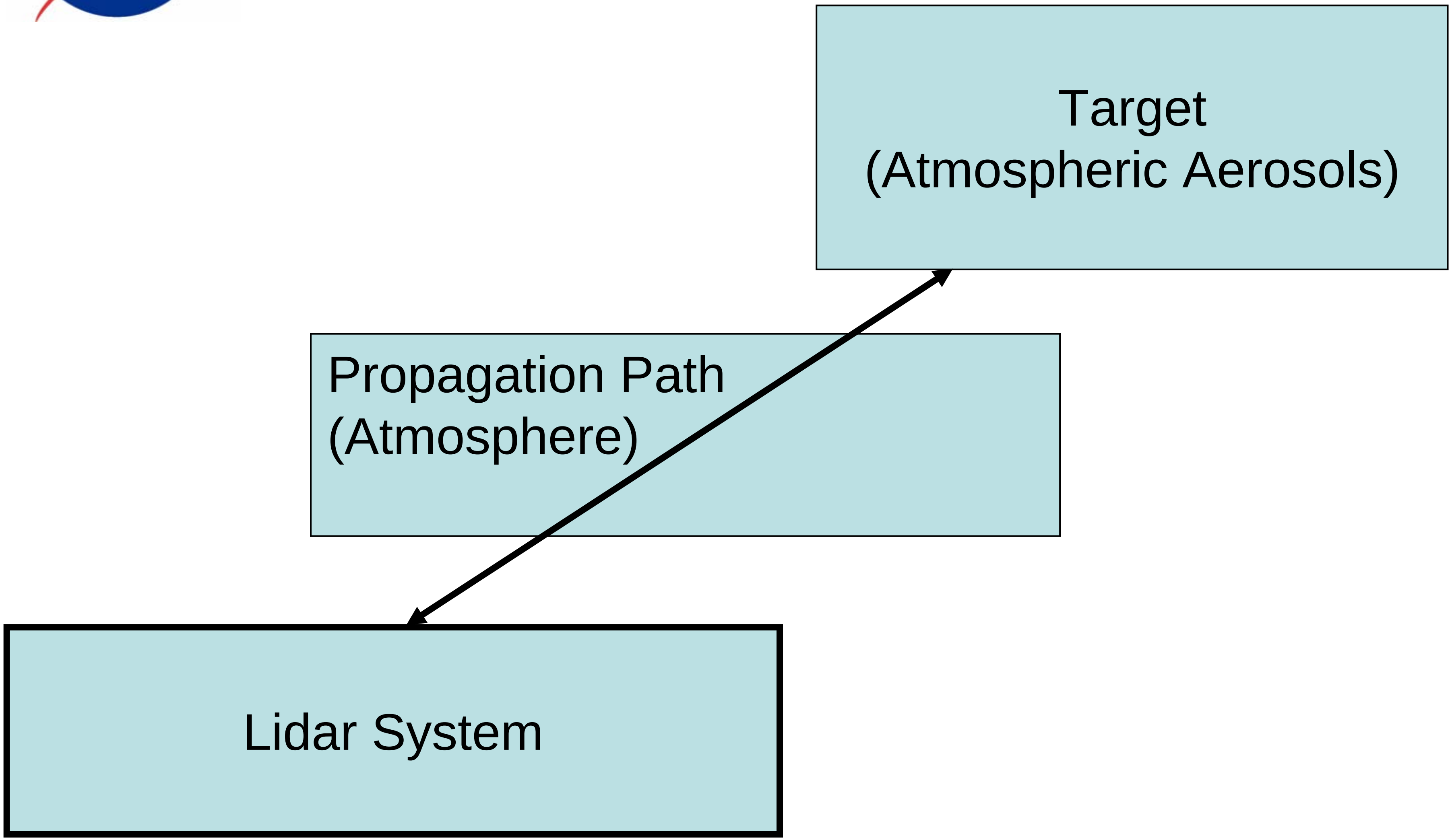
Project Motto 2

- Walk before you run

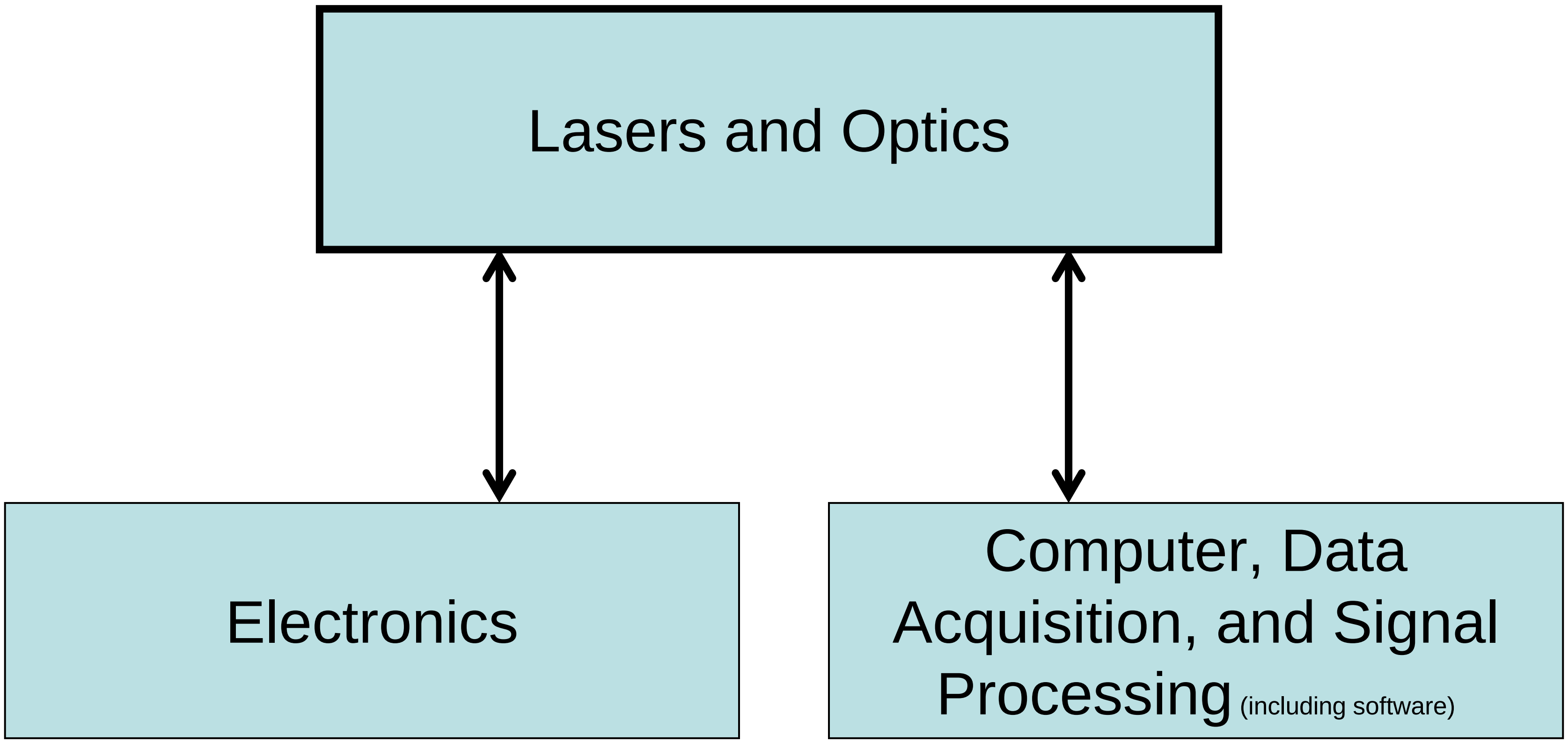
BACK UP

IIP – Scope of the Project

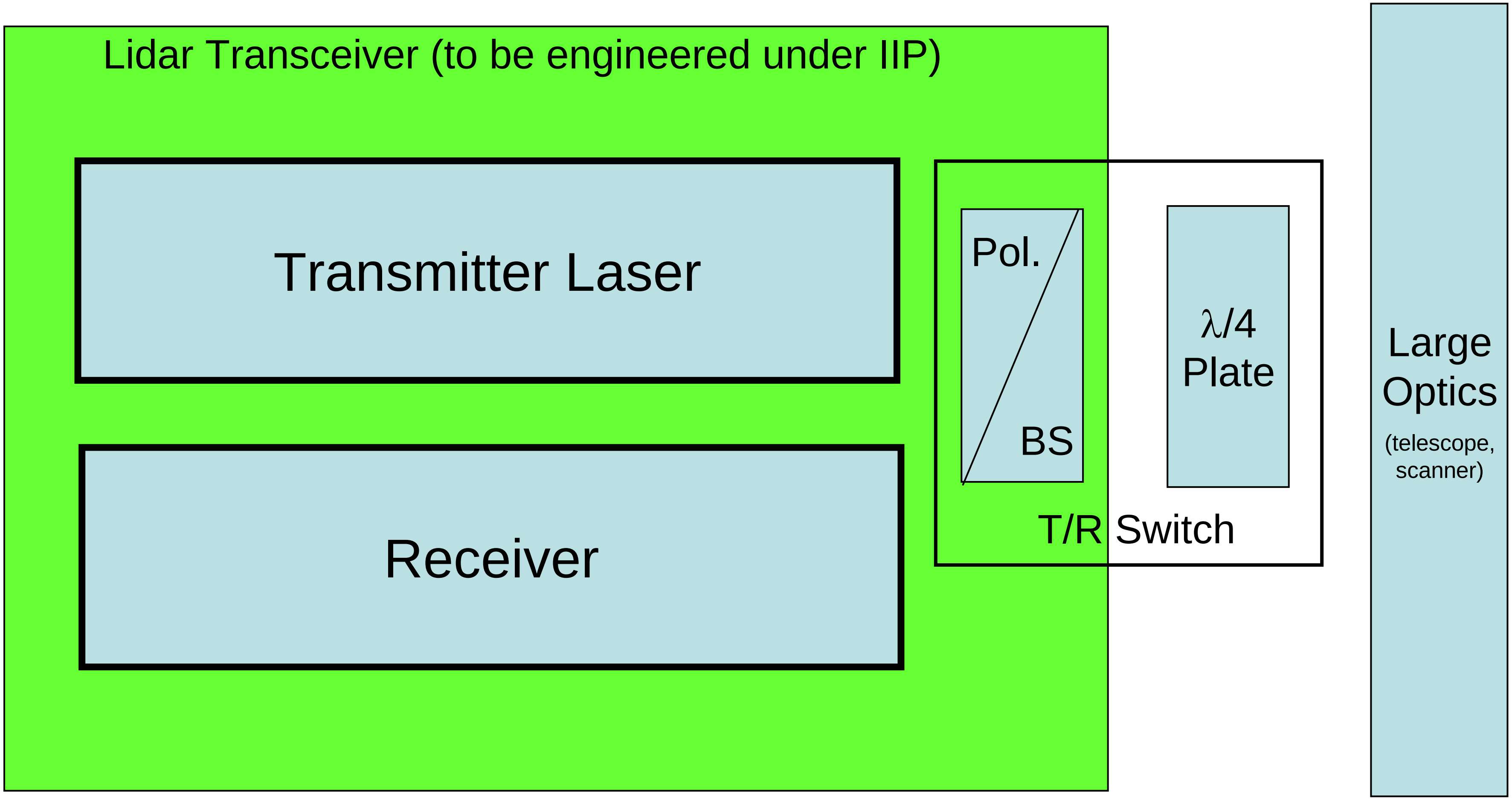
Pulsed Doppler Wind Lidar Measurement Scenario



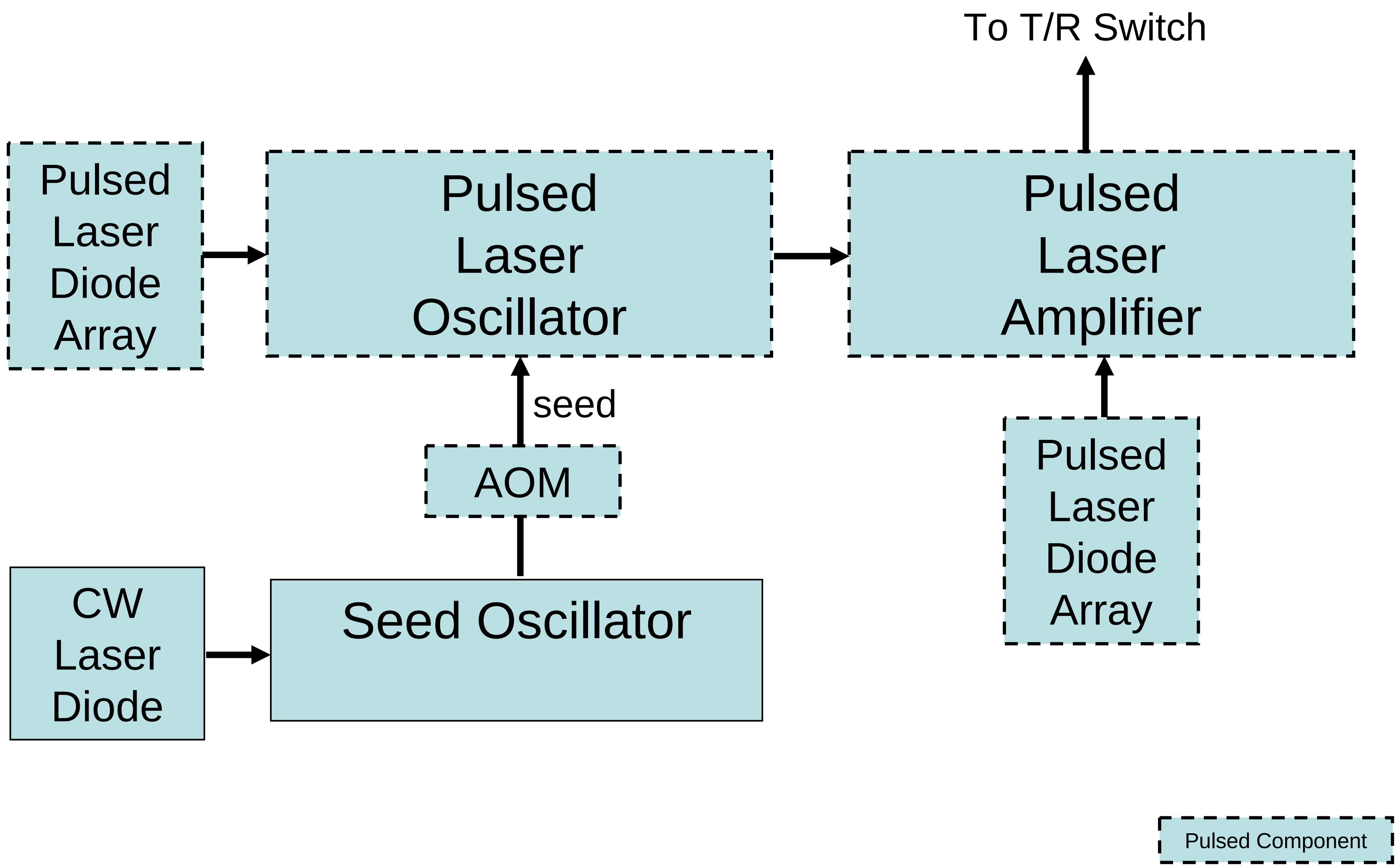
Lidar System



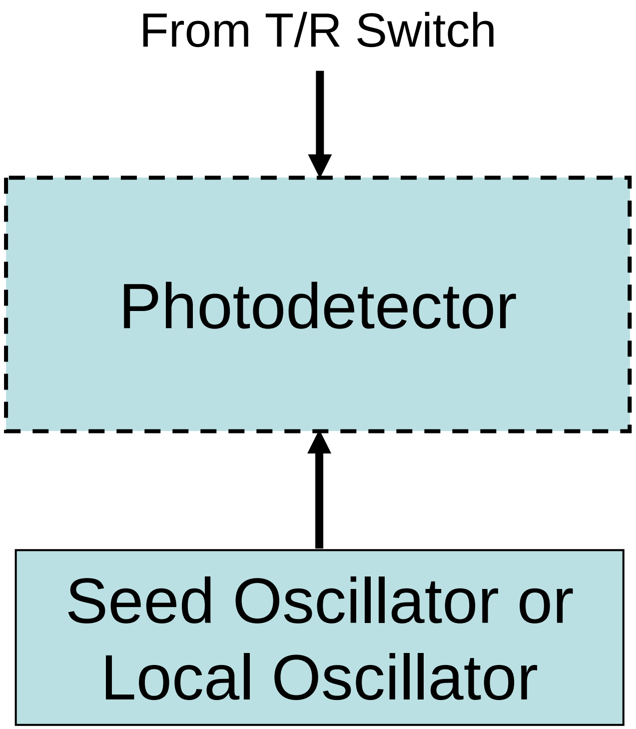
Lasers and Optics



Transmitter Laser



Receiver



Pulsed Component

Laser Design Considerations

- Laser wavelength
- Laser material
- Laser pumping geometry
- Laser cavity design
- Laser architecture

Why Ho:Tm:LuLiF

- Why Ho laser?
  - Tm lasers in 2-µm region have such a low gain cross-section (σ_{em}~10^{-20} cm^2) that efficient, high-energy laser amplification is impossible without the risk of laser crystal or associated optics damage.
  - Ho lasers have large enough stimulated emission cross-section (σ_{em}~10^{-19} cm^2) for effective amplification to obtain high-energy.
- Why co-doped?
  - Takes advantage of diode pumping for Tm lasers
  - Takes advantage of the efficient Tm 1:2 relaxation energy transfer process
  - Takes advantage of the high emission cross-section of Ho laser

Why Ho:Tm:LuLiF – Cont.

- Why fluoride?
  - Fluoride
    - Long upper laser level lifetime ~ 15 ms, store more energy
    - Low up-conversion loss
    - Higher emission cross-section
    - Naturally birefringent material, no depolarization loss
    - Negative dn/dT –> weak thermal lensing
  - Garnet
    - Isotropic
    - Excellent thermo-mechanical properties

- Why Lutetium?
  - Lanthanide series ions
    - Lutetium, Yttrium, Gadolinium
  - Lutetium
    - Lutetium – larger crystal field
      - larger manifold stark splitting -> Small thermal population of ground state

Laser Architecture
Master Oscillator Power Amplifier (MOPA)

- Energy requirement
  - Single oscillator can't produce required energy
- Beam quality
  - MOPA preserves the good beam quality
- Lifetime
  - Permits more derating of pump diodes
- Efficiency
  - Multiple pass amplifier improving the efficiency
- Optics Damage
  - Reducing intra-cavity fluence

Cavity Configuration

- Linear Cavity
  - Standing waves
  - Simple
  - Round trip - pass gain medium twice

- Ring Cavity
  - Traveling waves
  - No spatial hole burning in the gain-> single mode
  - Long cavity needed to obtain narrow linewidth
  - Beneficial for injection seeding through output coupler

Pumping configuration

- Pumping geometry
  - Side Pumping
    - Power scaling
    - Uniform pumping
  - End Pumping
    - Easy thermal management
    - Easy to mode match
    - Higher pump density
- Single Longitudinal Mode
  - Interferometric mode selection
  - Monolithic design, short cavity
  - Injection seeding

Optical Bench

- Two options:

    26.5 x 23.0 x 7 inch single side

    26.5 x 11.5 x 7 inch double sided
- The split can be done such that the receiver optics and the seed laser on one side, and the power Oscillator amplifier on the other.
- Optical bench is water cooled, enclosed and dry purged.